Fiji Department of Energy
Biofuels Development Unit

Fiji Institute of Technology
Faculty of Applied Sciences, Engineering and Maritime Studies (FASEMS)

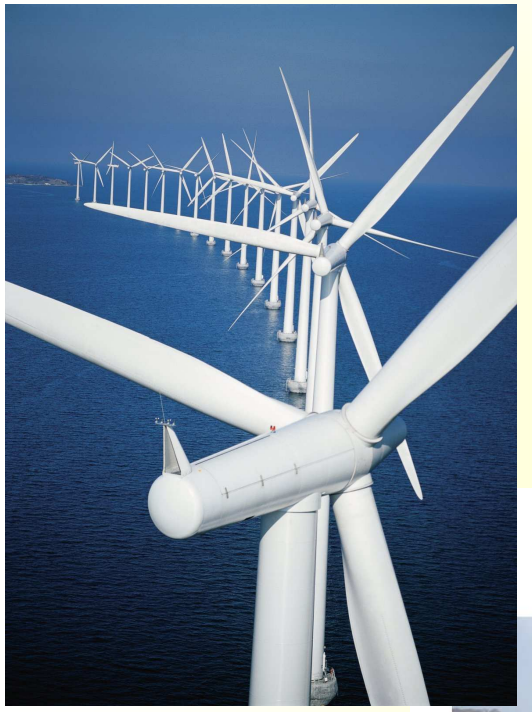
Coconut Oil as Fuel for Diesel Engines

Dr. Gilles Vaitilingom

BIOFUELS

- **Why ?**

RENEWABLE ENERGIES ☞ not for liquid fuels substitution



Biogas

Biomass Gasification

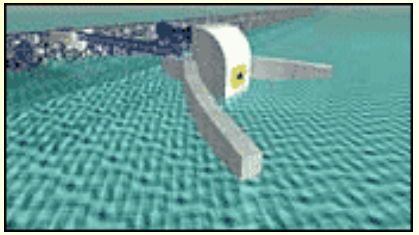
NEW AND RENEWABLE ENERGIES ☞ not for liquid fuels substitution

Solar Stirling engine

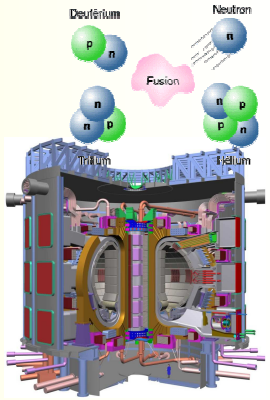
Geothermal

Pelamis (Ocean Power Delivery)

hydroliennes

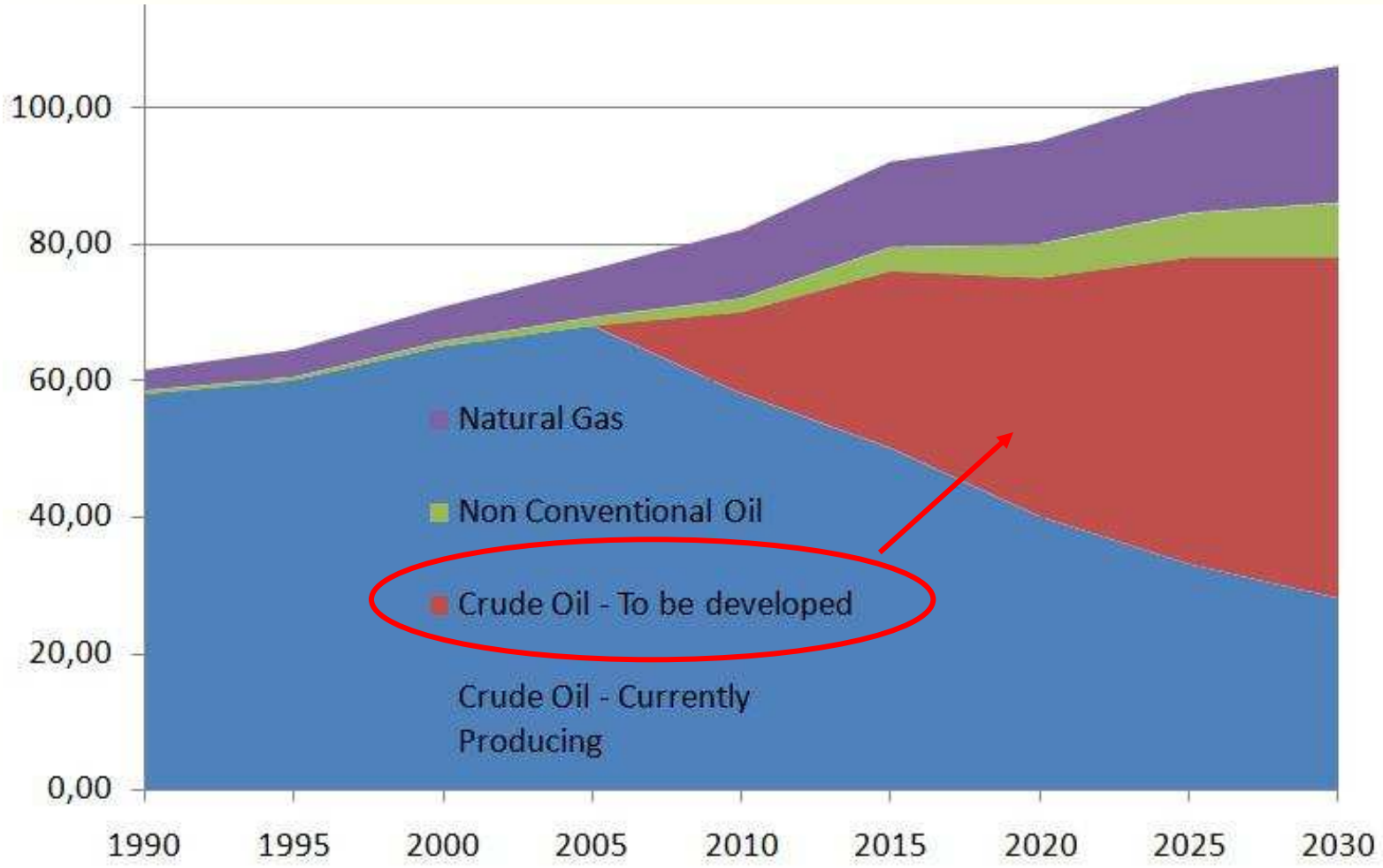


Energy from waves



Fusion : ITER

Updated Outlook for World in 2030



Source: IEA 2008

BIOFUELS FUNDAMENTALS

- **How ?**

BIOFUELS ????

BIOFUELS (1)

Fuels from Biomass ?

- Firewood

  >10 % of world energy consumption (# hydro & nuclear)

  In many countries: 80 % of total energy sector

- Biogas

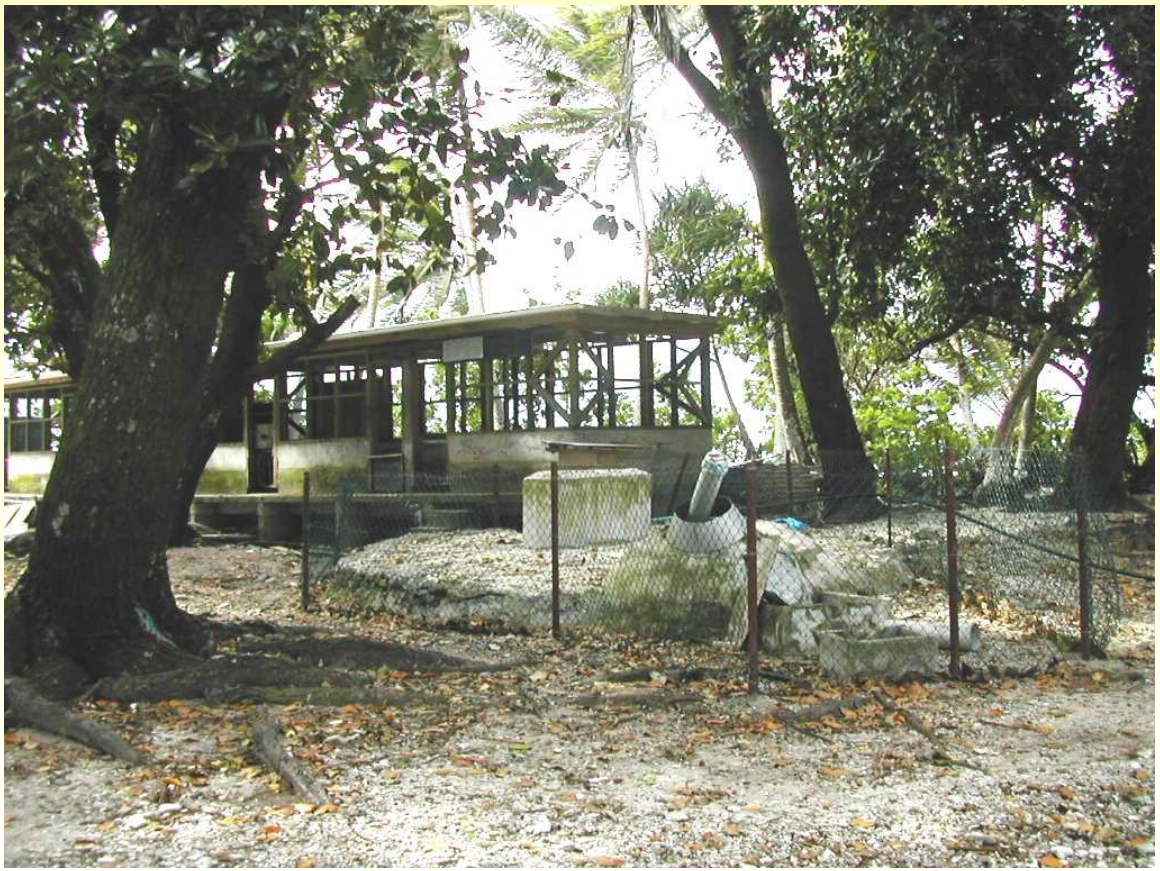
  Fermentation biodigestor ➔ CH4

  Gasification of wood, agro-residues ➔ CO, H2

BIOGAS

BIODIGESTOR – Natural gas for domestic purpose or small rural electrification (Wad Medani SUDAN)

BIOGAS



BIODIGESTOR – Natural gas for domestic purpose or small rural electrification (Amatuku – TUVALU)

GASIFICATION

Rice husk Gasifier (Indonesia)

Electricity from crops residues

BIOFUELS (2)

BioFuels: Liquid Substitutes of Petroleum products

- **ALCOHOLS** Ethanol from sugar cane
  sugar beat
  mais (corn)

  Substitute of gasoline ☞ HIGH GRADE FUEL

  BRASIL, USA, EUROPE

- **Derivatives: ETBE** octane enhancer
  EUROPE

BIOFUELS (3)

Bio-Fuels: Liquid Substitutes of Petroleum products

- **VEGETABLE OILS** PALM, COPRA COTTONSEED, PEANUT, RAPESEED, SUNFLOWER, SOJA,...

  Substitute of Diesel oil

  EUROPE, South Pacific (New Caled., Fiji, Vanuatu,…), Africa, Latin America,…

- **BIODIESEL: Methyl and Ethyl Esters of Veg. Oils**

  EUROPE (France: 4000 millions of liters rape&sunf / year)

BIOFUELS INTEREST

Biofuels are environmentaly friendly :

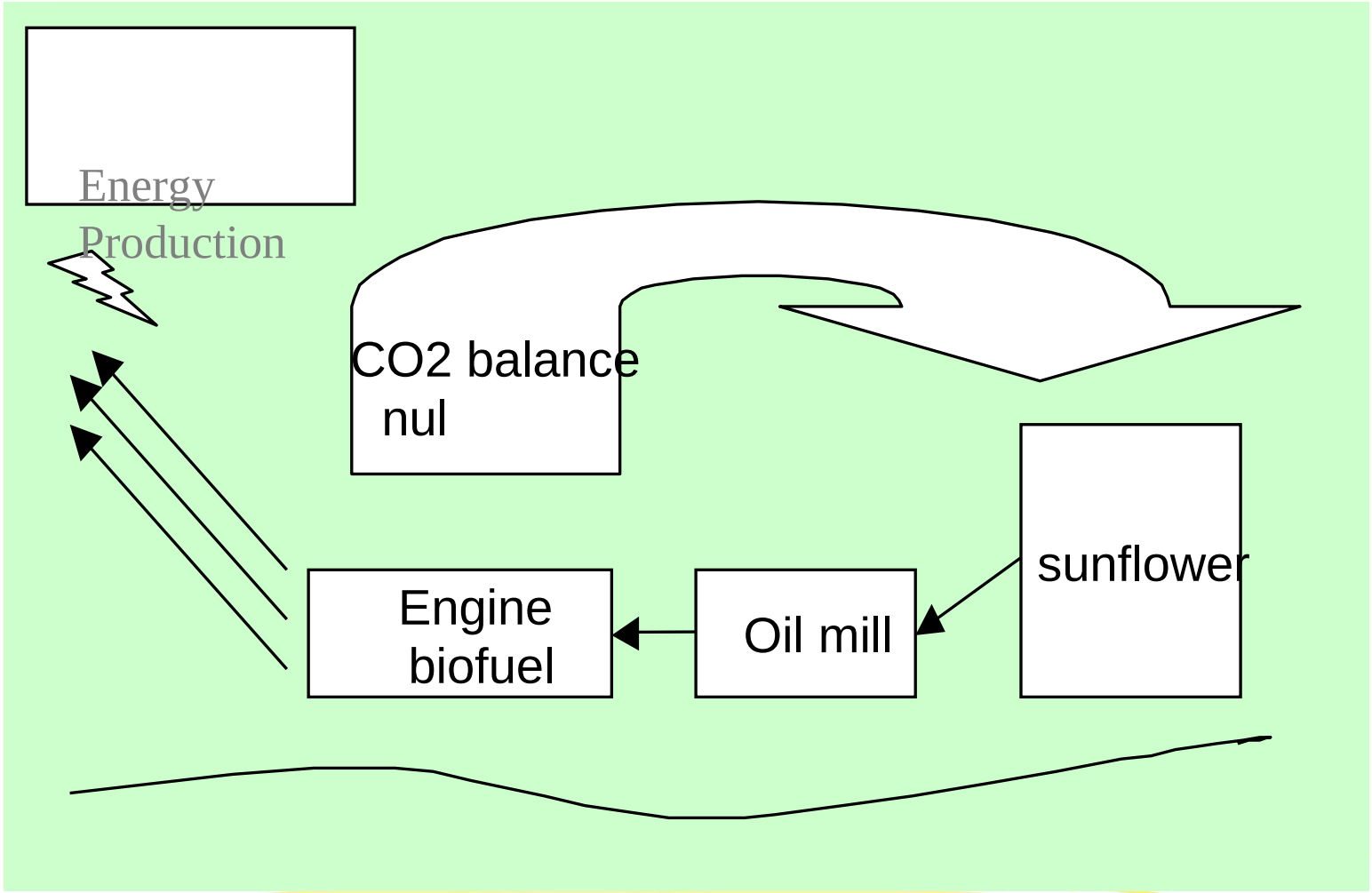
- **biofuels coming from agriculture don’t increase CO2 rate in the atmosphere** **(TTW: tank to wheel)**

1000 litres of sunflower oil = 3.2 tonnes CO2 saved

- **pollutants at the exhaust:**

- are respecting the legal limits in force prescribed for diesel and gasoline

- are benefiting of depolluting exhaust systems development


Energy Production
CO2 balance nul
sunflower
Oil mill
Engine biofuel

VEGETABLE OILS AS FUEL

- Characteristics close to diesel oil

LCV coconut oil: 41 MJ/kg
LCV Diesel oil: 44 MJ/kg

Density coconut oil: 0.92
Density Diesel oil: 0.83

- History:

  - Mr. Diesel himself in 1900
  - World War II
  - Banned from research in the 50’
  - interest renewed at the end of 70’
  - But: last International Congress in 1982.

VEGETABLE OILS AS FUEL
Why so few applications ?

- higher cost than diesel ☞ case of most renewable

  But new position with > USD 70/barrel

- too different to respect fuel standards

  New standards on the way: Germany, and soon Fiji

- considered as high income agri-products Only for some "niche"

- " Food versus energy" New concept of Sustainable development

- Coconut Oil ! Not to be compared to a cheap, common and stinking product New consideration → USD 70 for 159 liters

COCONUT OIL AS FUEL

Diesel Engine
•Theory

HISTORY OF VEGETABLE OILS AS FUEL

SINCE NEOLITHIC PERIOD : 9000 before J.C.

BUT: PETROL LAMPS IN 1853 !

HISTORY OF DIESEL ENGINE

Rudolf DIESEL (1858 – 1913)

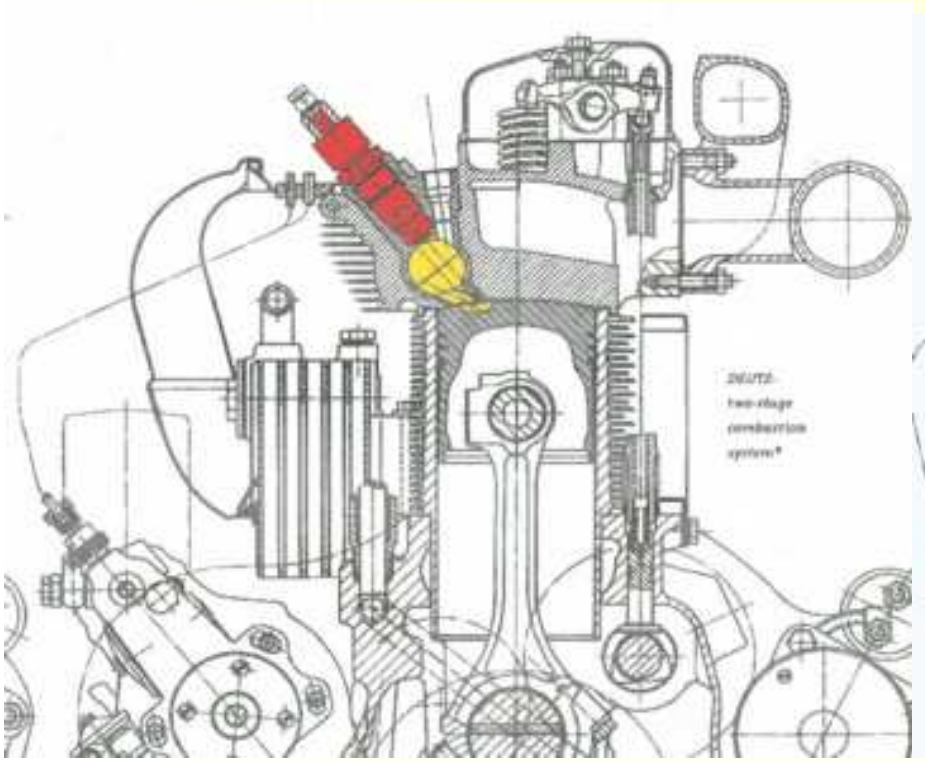
He designed it for pulverized coal as fuel

It is a « long stoke » engine, inspired by the adiabatic principle.

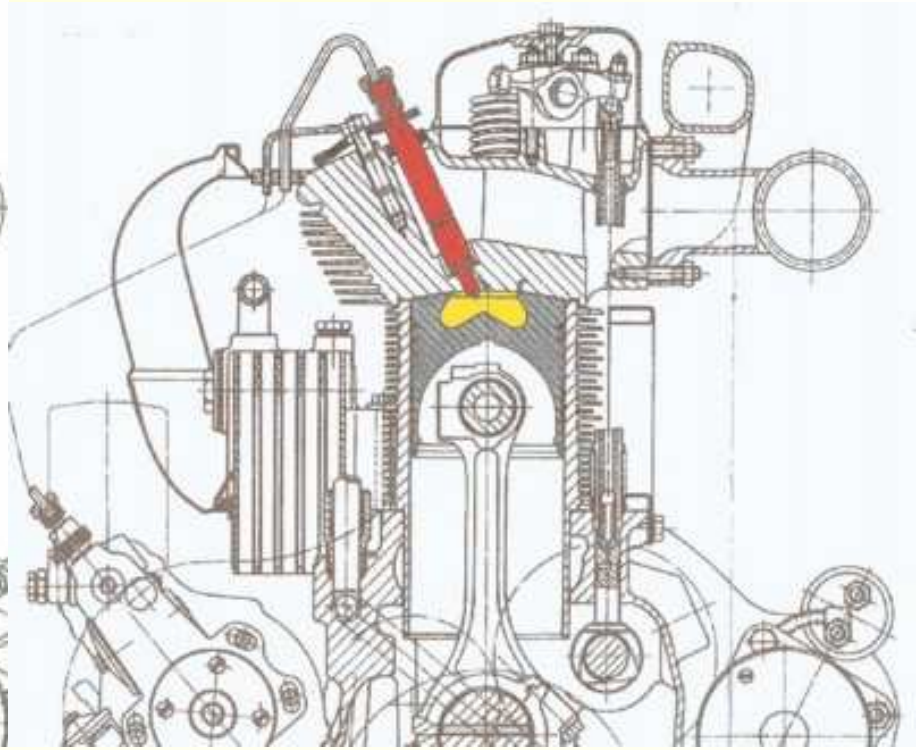
ARCHITECTURE OF DIESEL ENGINES

THE TWO TYPES OF DIESEL ENGINE

INDIRECT INJECTION



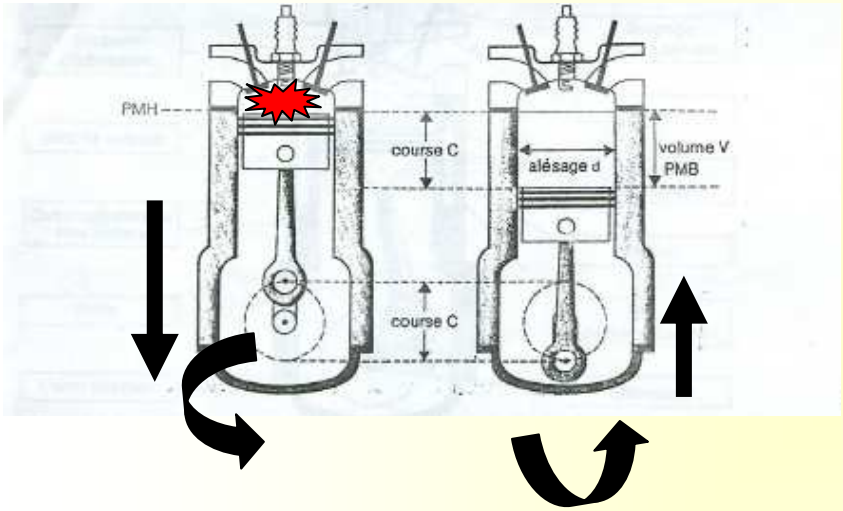
DIRECT INJECTION



DEUTZ AIR COOLED ENGINES: 912, 914 AND 912W

ARCHITECTURE OF DIESEL ENGINES

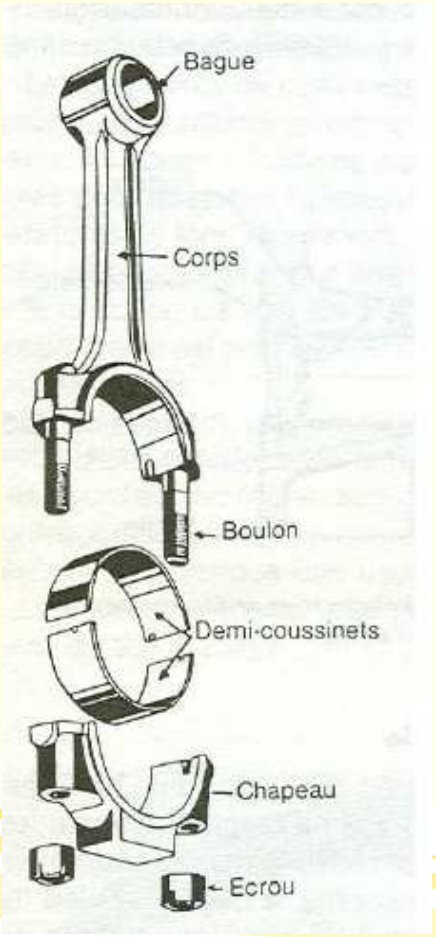
PISTON AND CONNECTING ROD



1. PISTON IS PUSHED DOWNWARD BY THE PRESSURE DUE TO THE COMBUSTION

2. THE ROD ROTATE THE CRANKSHAFT AND MOVE THE PISTON UPWARD

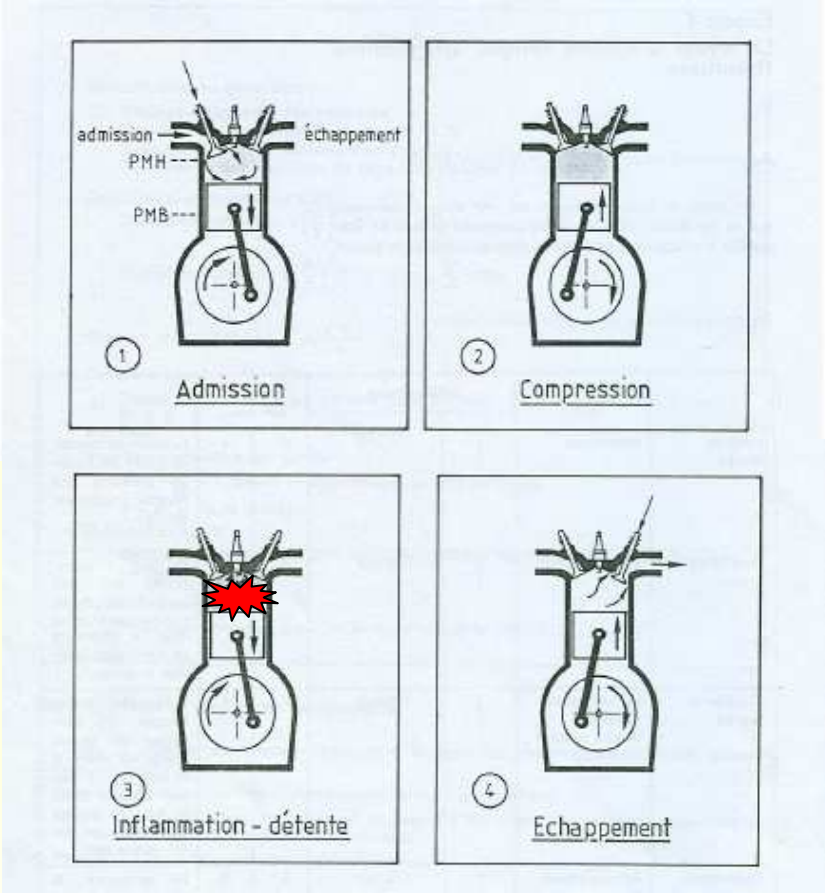
3. THE ROTATION OF THE CRANKSHAFT IS CREATING TORQUE AND POWER



ARCHITECTURE OF DIESEL ENGINES

FOUR STROKE

1. AIR IS PUMPED BY THE PISTON. INLET VALVE IS OPEN. OULET VALVE IS CLOSED



2. AIR IS COMPRESSED BY THE PISTON. INLET VALVE AND OULET VALVE ARE CLOSED

3. IGNITION OCCURED. THE PISTON IS PUSHED BY THE PRESSURE. INLET VALVE AND OULET VALVE ARE CLOSED

4. THE PISTON IS PUSHING OUT BURNED GAS. INLET VALVE IS CLOSED. OULET VALVE ARE OPEN

ARCHITECTURE OF DIESEL ENGINES

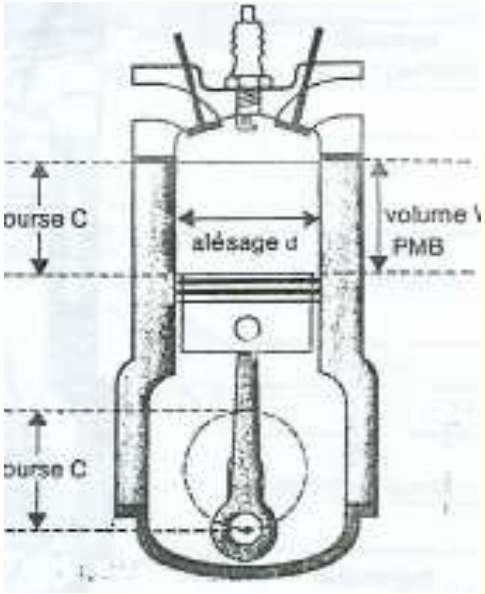
FOUR STROKE

MOVIE 1: ARCHITECTURE

MOVIE 2: 4 STROKE CYCLE AND COMBUSTION PROCESS

DIESEL ENGINES

FUNDAMENTALS



$$V_u = c \times \frac{\pi d^2}{4}$$

d: diameter of the cylinder (bore)

c: movement of the piston (stoke)

Vu: displacement

$$V_t = V \cdot n$$

Total displacement: Vu x n (n: number of cylinder)

$$\rho = \frac{V+v}{v}$$

V: displacement

v: volume of combustion chamber

ρ: compression ratio

$$P = \frac{W}{t} = C \cdot \frac{2\pi N}{60} = C \cdot \omega; \qquad [\mathrm{W = Nm \,.\, s^{-1}}]$$

C: torque (Nm)

ω: revolution (radian/s)

N: revolution in rpm

W: energy (J)

P: Power (Watt)

DIESEL ENGINES

FUNDAMENTALS

Sfc: specific consumption (g of fuel/kWh)

How many g. of this fuel are necessary to produce 1 kWh in this engine

$$\eta = 3.6 / Sfc \times LCV$$

η: global efficiency

Ratio of mechanical energy on the shaft / energy in the fuel

LCV: lower calorific value (MJ/kg)

1 kWh = 3,6 MJ

TO DAY: PETROL ENGINES 30 % TO 40 %

DIESEL ENGINES 32 % TO 45 % (50 % large Diesel)

COCONUT OIL AS FUEL

Coconut oil in Diesel Engine

- **quality of coconut oil as fuel**

QUALITY OF VEGETABLE OILS AS FUEL

German norme DIN 51605 for rapeseed.

LTV-Work-Session on Decentral Vegetable Oil Production, Weihenstephan Quality Standard for Rapeseed Oil as a Fuel (RK-Qualitätsstandard) 05/2000				in Cooperation with:
Properties / Contents	**Unit**	**Limiting Value min.**	**max.**	**Testing Method**
charcteristic properties for Rapeseed Oil				
Density (15 °C)	kg/m³	900	930	DIN EN ISO 3675 DIN EN ISO 12185
Flash Point by P.-M.	°C	220		DIN EN 22719
Calorific Value	kJ/kg	35000		DIN 51900-3
Kinematic Viscosity (40 °C)	mm²/s		38	DIN EN ISO 3104
Low Temperature Behaviour				Rotational Viscometer (testing conditions will be developed)
Cetane Number				Testing method will be reviewed
Carbon Residue	Mass-%		0.40	DIN EN ISO 10370
Iodine Number	g/100 g	100	120	DIN 53241-1
Sulphur Content	mg/kg		20	ASTM D5453-93
variable properties				
Contamination	mg/kg		25	DIN EN 12662
Acid Value	mg KOH/g		2.0	DIN EN ISO 660
Oxidation Stability (110 °C)	h	5.0		ISO 6886
Phosphorus Content	mg/kg		15	ASTM D3231-99
Ash Content	Mass-%		0.01	DIN EN ISO 6245
Water Content	Mass-%		0.075	pr EN ISO 12937

QUALITY OF COCONUT OIL BIOFUEL
Proposal of a quality standard

Quality standard for Coconut oil as fuel (proposal)				
Properties/content	Unit	Min.	Max.	Test method
Characteristic properties				
Density at 25℃	Kg/m^3	0,915	-	ASTM D1298
Flash Point	℃	210	-	ASTM D93
Calorific value	MJ/kg	37	-	
Viscosity (Kin. @ 40℃)	mm^2/s	-	30	ASTM D445
Carbon residue	Mass %	-	0,40	ASTM 4530
Sulphur content	mg/kg	-	20	ASTM D5453
Cetane Index		40	-	ASTM D4737
Variable properties				
Total contamination	mg/kg	-	25	ASTM 5452
Acid value	mg KOH/g	-	10	ISO 660
Oxidation stability (110℃)	h	4		ASTM D2274
Phosphorous content	mg/kg	-	15	ASTM D323
Ash content	Mass %	-	0,02	ISO 6245
Water content	Mass %	-	0,075	ISO 12937
Source: *G. Vaitilingom,J. Cloin. Pacific Regional Bioenergy Workshop 17 – 20 Nov. 2008 in Nadi, Fiji Islands*				

CRUDE COCONUT OIL IN MODIFIED DIESEL ENGINE

2004 GENSET. 300KVA
Power Station of ENERCAL (Utility) New Caledonia

The pre-filtered coconut oil (drum on the left) is pumped by an electrical driven-pump (between drum and filter) and pushed through a flow line bag-filter (on the right).
The hose at the bottom right is connected to the coconut oil main tank of the generator.

COCONUT OIL AS FUEL

Coconut oil in Diesel Engine

- **combustion of coconut oil as fuel**

Coconut oil Biofuel is not Diesel Fuel and must be used in adapted engines only!

VEGETALES OILS AS FUEL FOR DIESEL ENGINES

Testing bench in Cirad

(John Deere 200 HP)

Carbon deposits

on top of pistons

VEGETALES OILS AS FUEL FOR DIESEL ENGINES

WHY ?

Piston after 200 hrs. with diesel fuel at idle speed no load

Piston after 21 hrs. with sunflower oil at idle speed no load

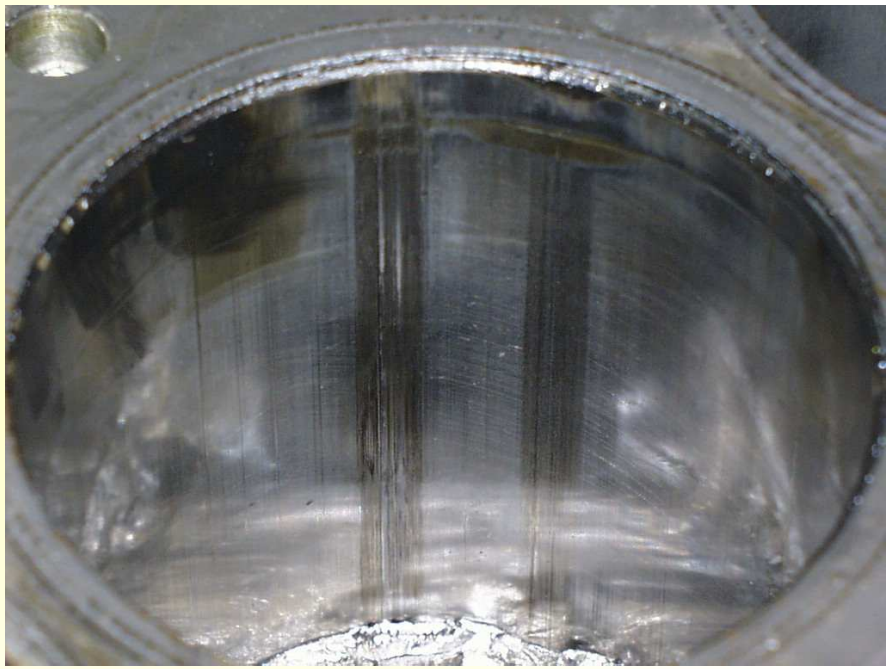
CONSEQUENCES (2)

CARBON DEPOSIT

Figure 10 - encrassement typique dû aux huiles végétales (piston de moteur à injection directe, 10 heures de ralenti à vide, huile de tournesol raffinée)

MECHANICAL DAMAGES

Injection pumps, rings, cylinder,…

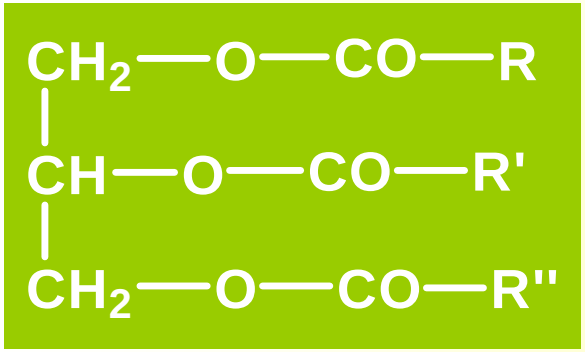


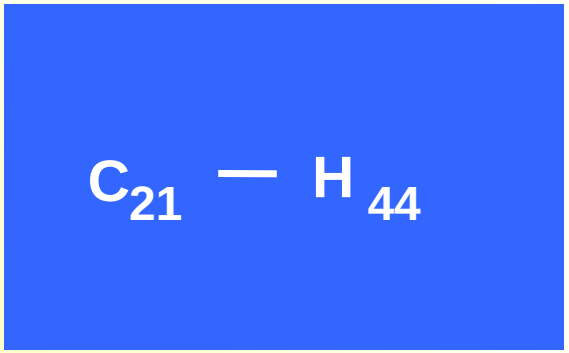
CONSEQUENCES (3)

CARBON DEPOSITS

nozzle, valves,…

VEGETABLE OILS / DIESEL FUEL





TRIGLYCERIDES > 90 %

HEATING VALUE : 35 – 39 (MJ/kg)

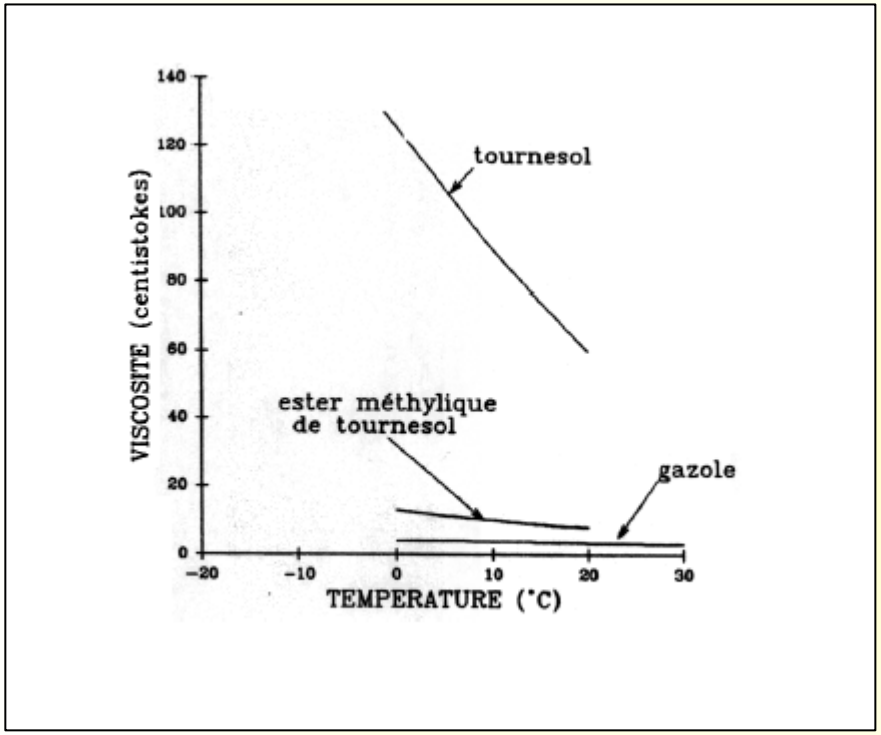
DENSITY : 0.91 – 0.94 (20°C).

HEATING VALUE : 43 – 44 (MJ/kg)

DENSITY : 0.83 (20°C).

CONSTRAINTS (1)

CONTRAINTES PHYSIQUES



DIESEL	:	- 35 ℃
RAPESEED	:	- 11 ℃
Coconut Oil	:	+ 23 ℃

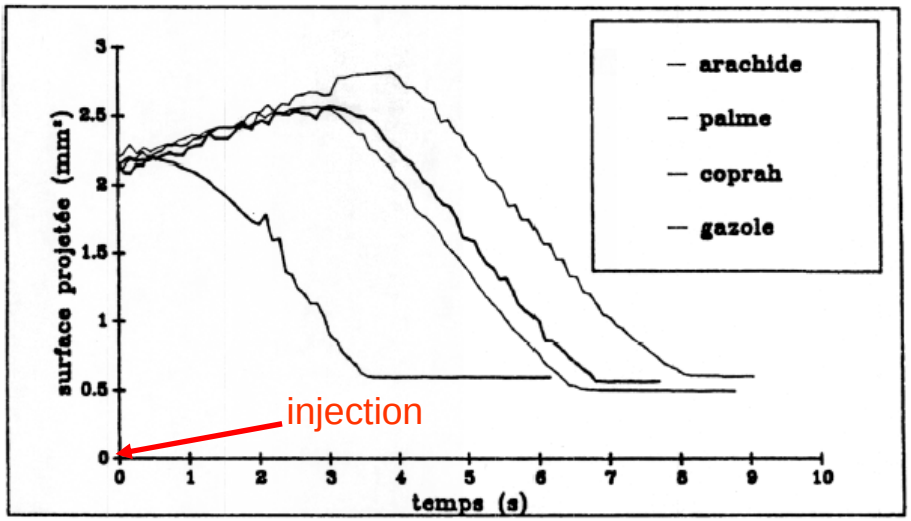
VISCOSITY AT 40 °C : gazole < 5 coconut oil = 25 (mm_2/s)

SENSITIVITY to COLD COND.

Beginning of solidification

CONSTRAINTS (2)

CONTRAINTES CHIMIQUES



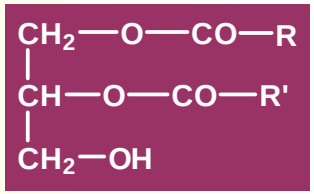
1.EVAPORATION OF DROPLETS at 630 °C

At 440 °C, only Diesel is totaly evaporated.

3. BAD PROPERTIES : siccativity
(sunflower : yes, Coconut oil : no)

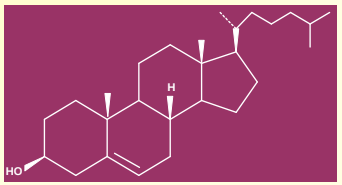
2. MINOR COMPONENTS : GUMS, WAXES,…

- **partial Glycerides (1 – 10 %)**



- **Free Fatty Acids (0.5 – 5 %)**

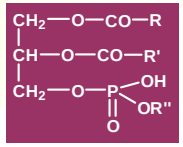
- **non-saponifiables, pigments… (0.5 – 2 %)**



Sterols

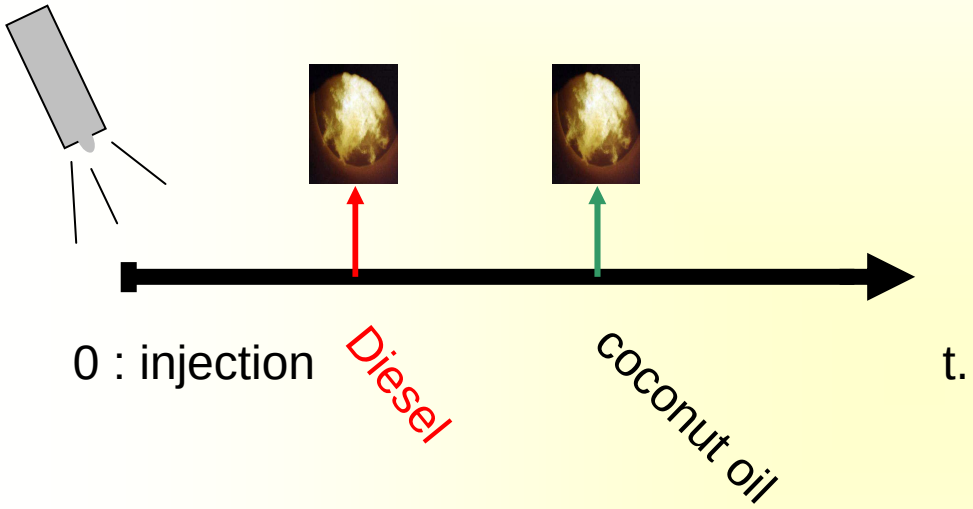
tocopherols

- **Phosphatides (0.1 – 1 %)**

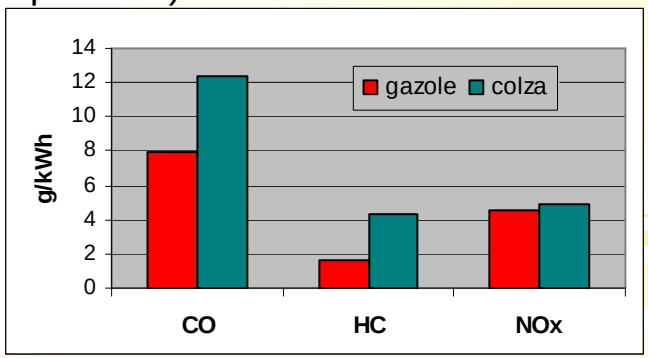


CONSEQUENCES

1. LONGER IGNITION DELAY



2. BAD COMBUSTION (spoiling lubricant, pollution)



3. CARBON DEPOSITS

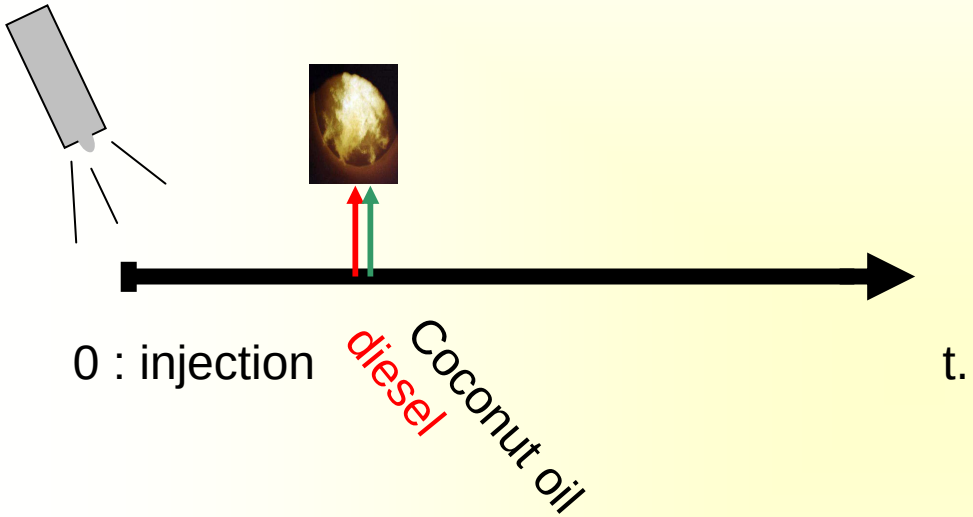
Figure 10 - encrassement typique dû aux huiles végétales (piston de moteur à injection directe, 10 heures de ralenti à vide, huile de tournesol raffinée)

4. MECHANICAL DAMAGE

Injection , rings, cylinder liner,…

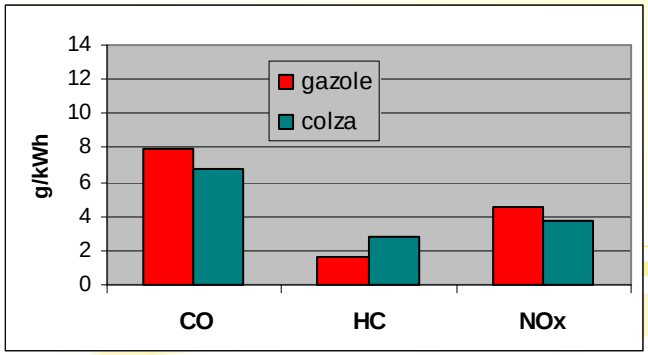
BUT… IF TEMPERATURE IS HIGH ENOUGH (> 500℃)

1. IGINITION DELAYS ARE EQUIVALENT



3. NO CARBON DEPOSITS

2. COMPLETE COMBUSTION



4. NO MECHANICAL DAMAGE

WHAT TEMPERATURE IS IT ?

1. TEMPERATURE OF THE COCONUT OIL ? NO

Except better viscosity -> better injection

2. TEMPERATURE OF THE ENGINE ? NO

it has no effect !

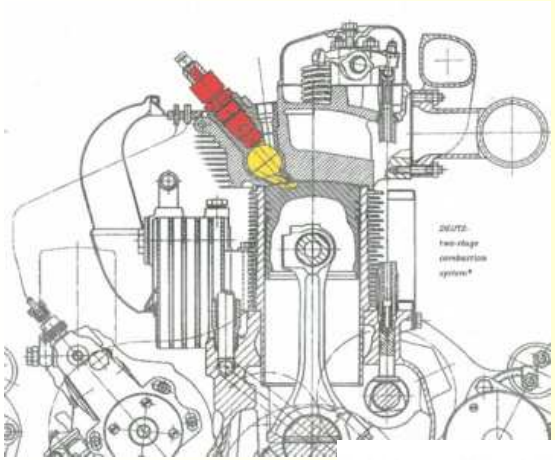
IT IS THE TEMPERATURE OF THE COMBUSTION CHAMBER

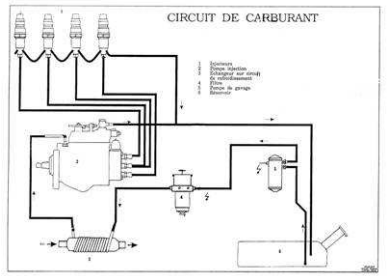
It is the average mean temperature of the cycle. It determines the exhaust temperature.

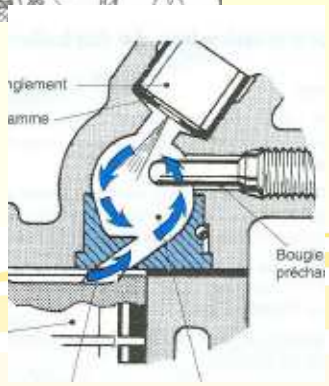
HOW IS IT POSSIBLE TO OBTAIN THE REQUESTED TEMPERATURE IN ORDER TO USE CNO ?

INDIRECT INJECTION : YES

As soon as engine idle Tmoy > 500 ℃



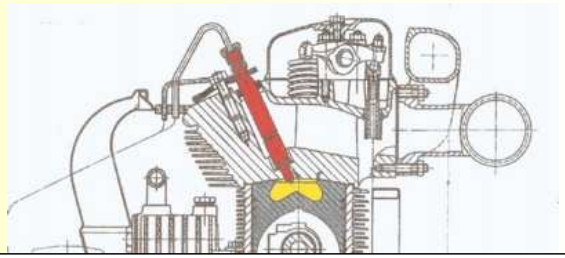


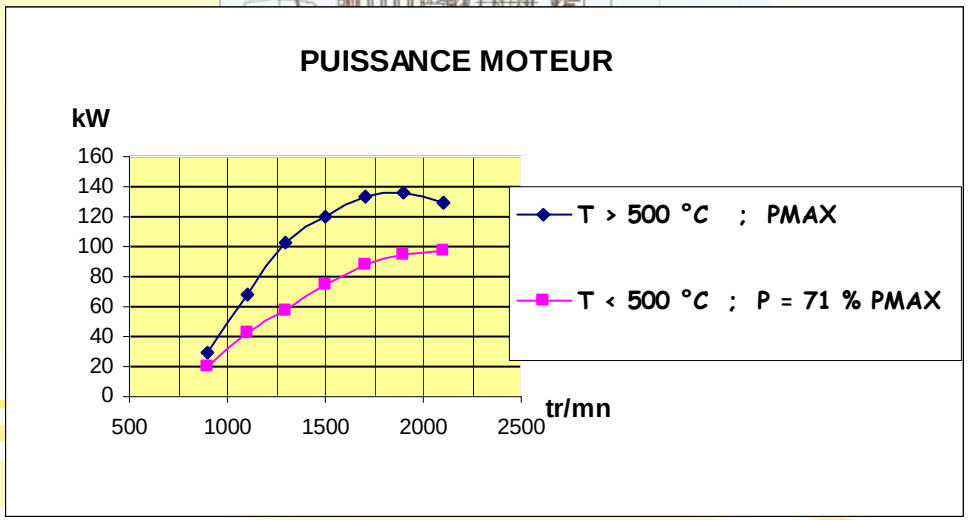


DIRECT INJECTION : YES, IF

Power > 70 % of MAX.

If not NO ! or in MODIFIED ENGINE



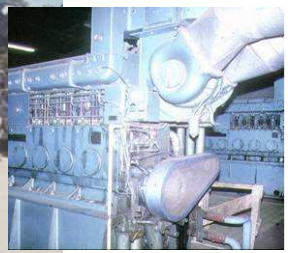


BUT IT IS POSSIBLE !!!

EXAMPLES OF PURE VEGETABLE OILS USES

DIESEL INJECTION INDIRECTE

DIESEL INJECTION DIRECTE



Principe de la modification

Exemple : FIAT 80 ch.

COCONUT OIL AS FUEL

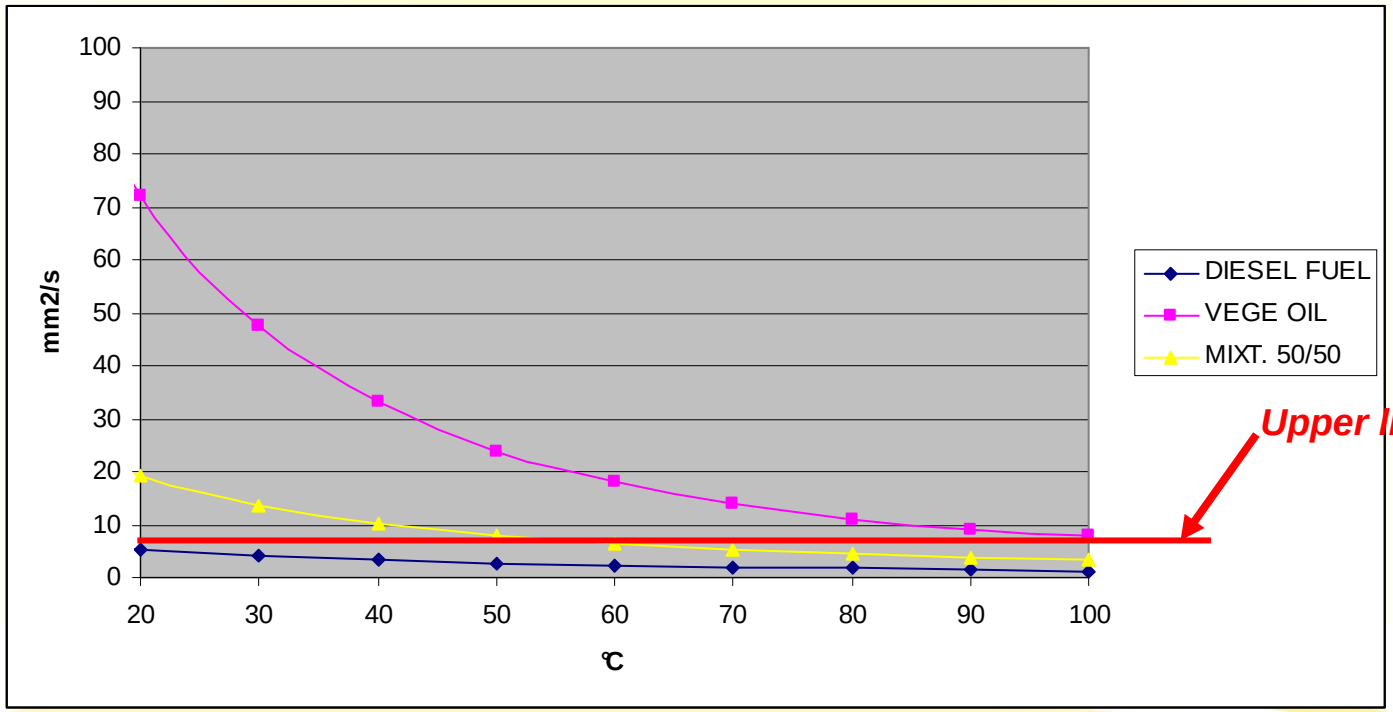
Coconut oil in Diesel Engine

- **adaptation to reduce the viscosity**

COCONUT BIOFUEL TRAINING
adaptation to reduce the viscosity

Filters, injectors, injection pumps, … have been designed for Diesel Fuel use (ref. 40℃). A too high viscosity may reduce flow and can damage injection pump.

(MIXTURES ARE USEFUL ONLY TO REDUCE VISCOSITY)



COCONUT BIOFUEL TRAINING

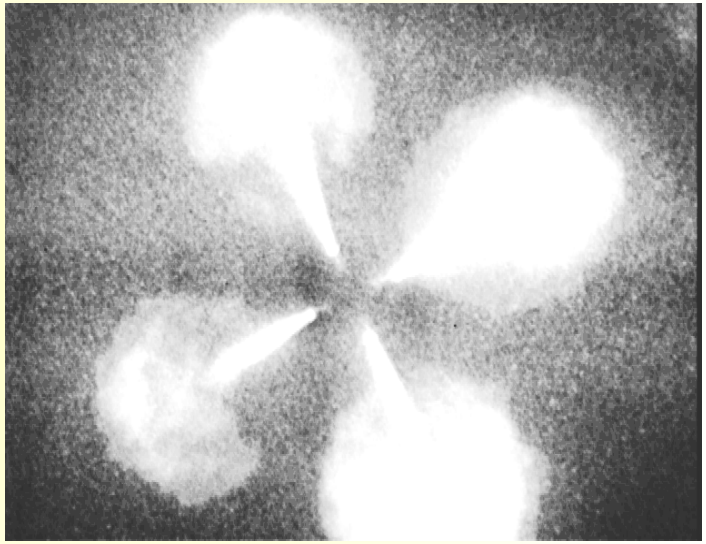
Water heat exchanger to increase coconut oil temperature

COCONUT OIL FUEL

Coconut oil in Diesel Engine

- **settings of opening pressure of injectors**

COCONUT OIL FUEL



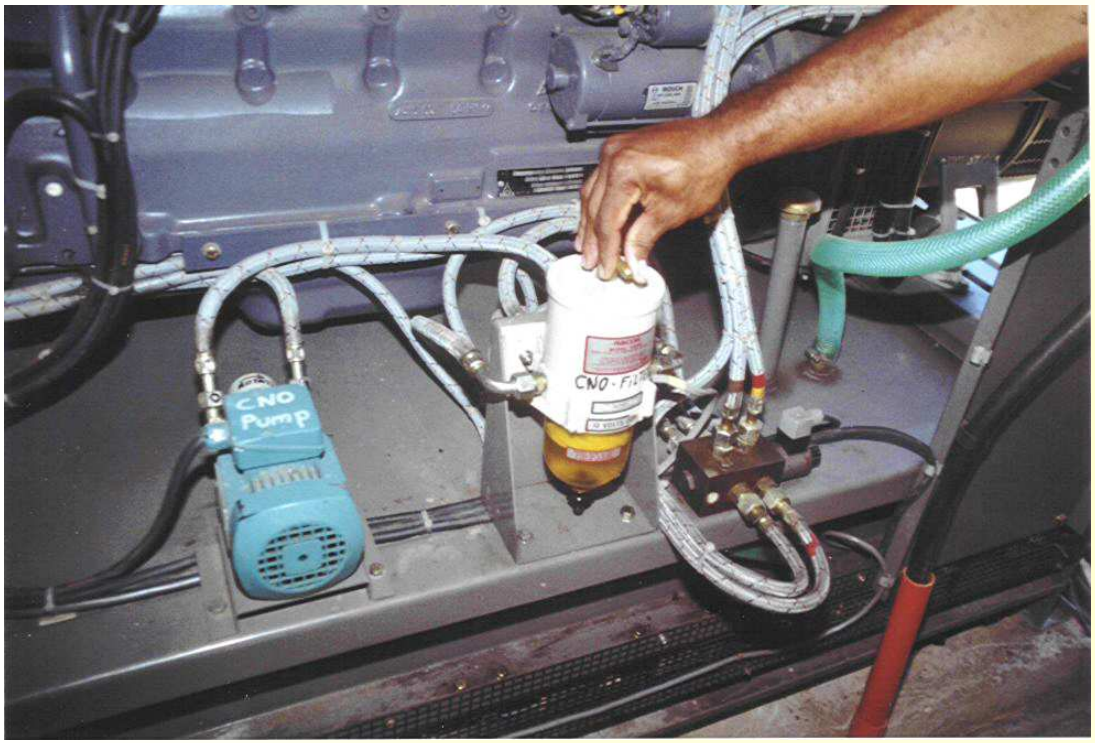
IDI: opening pressure 200 bars ; DI opening pressure 300 bars

COCONUT OIL FUEL

Coconut oil in Diesel Engine

- **adaptation of the fuel filtration**

COCONUT OIL FUEL



If coconut oil temperature can be under 100℃ => la rger surface of filtration

If coconut oil can become solid => heated filters and feeding lines

COCONUT OIL FUEL

Coconut oil in Diesel Engine

- **adaptation of the tank**

COCONUT OIL FUEL
adaptation of the tank

AC electrical heaters under the coconut oil tank and inside the tank

COCONUT OIL FUEL

Coconut oil in Diesel Engine

- **modification of Direct injection engines**

PISTON

BEFORE

ADAPTATION

NOZZLE

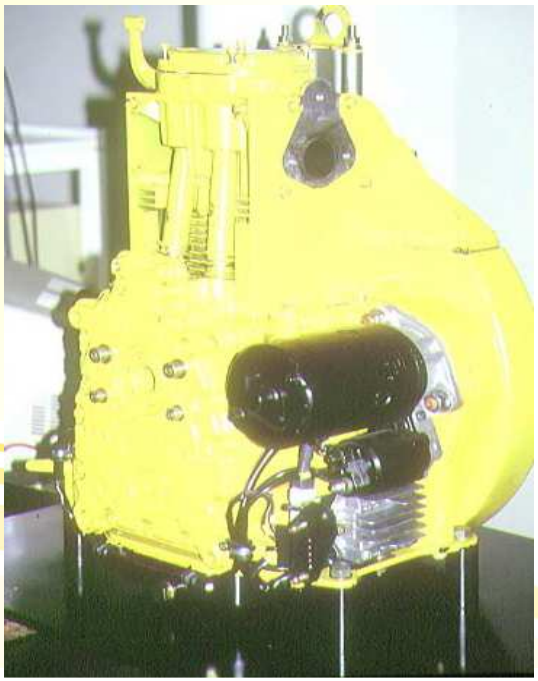
AFTER ADAPTATION

PISTON DESIGN

(DIRECT INJECTION)

HATZ ENGINE

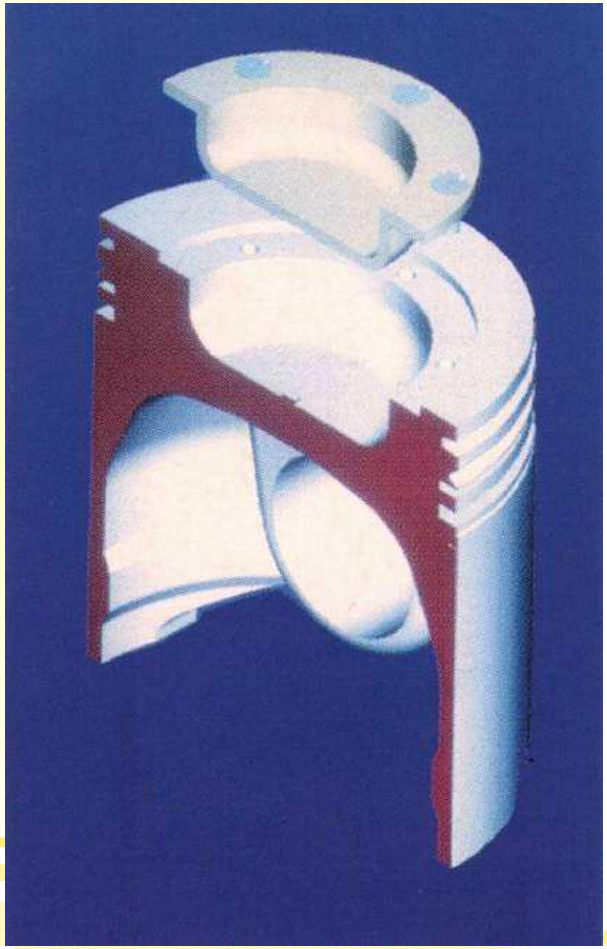
(DIRECT INJECTION)



Suva.

itute of Tec

- Piston John Deere
- mot. 4039
- CAO : ProEngineer
- Calculs : éléments finis en thermo-élasticité
- 1992



HUILES VEGETALES NATURELLES BIOCARBURANT EXEMPLES

Principe de la modification

Exemple : FIAT 80 ch.

LES HUILES VEGETALES BIOCARBURANT EXEMPLES

Tractor New Holland 150 ch.
Albi, France, **sunflower**

Tractor Deutz 75 ch.
Toulouse, France, **rapeseed**

Tractor Yumz (Camagüey - Cuba)

Spare Piston

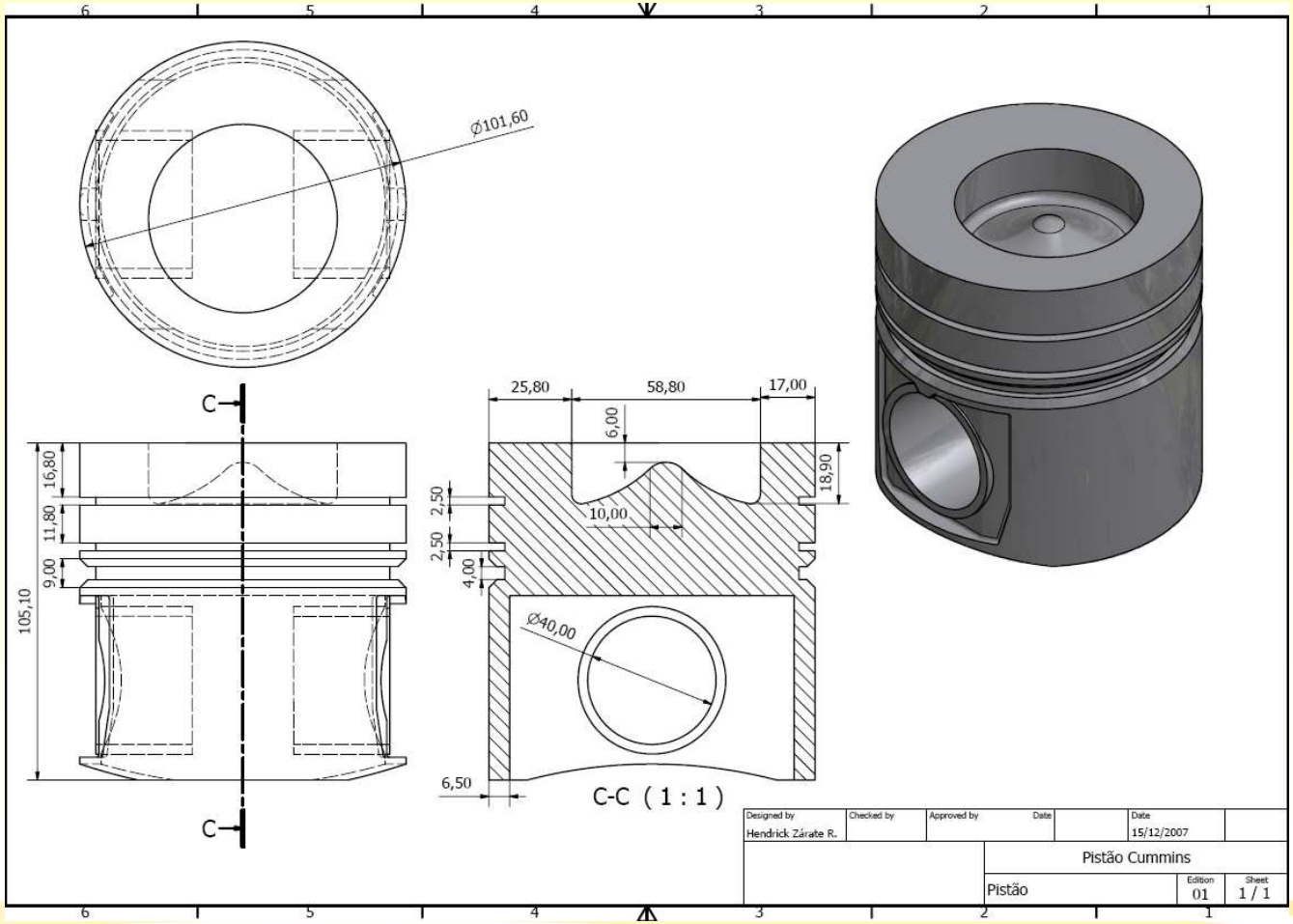
modified Piston

Tractor Biocombustible Yumz D-65 M, Sunflower or soja

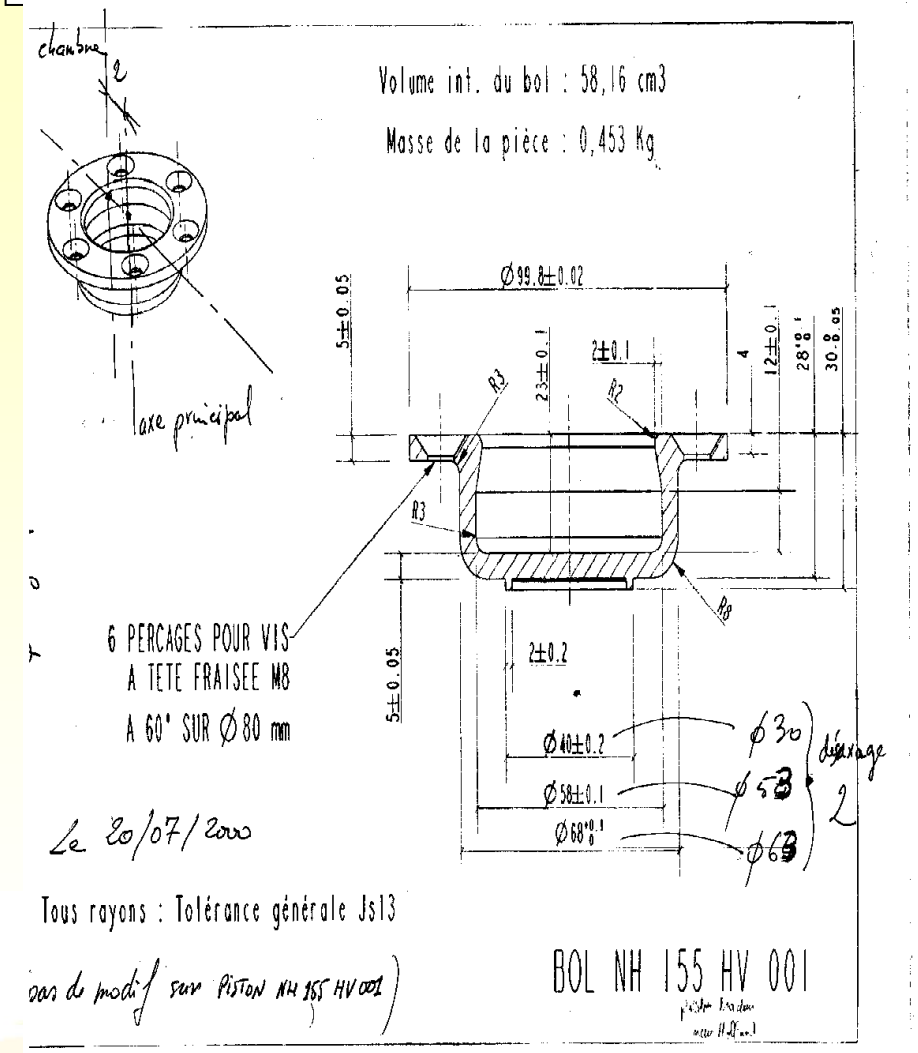
UBPC Victoria 2, Camagüey - CUBA

UBPC Victoria 2

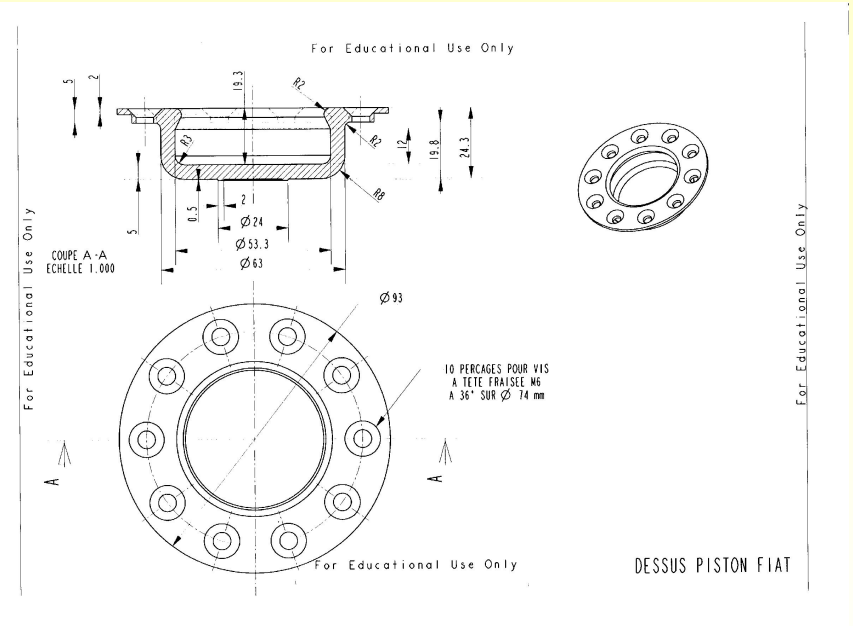
Example of combustion chamber



Example of combustion chamber



Example of combustion chamber

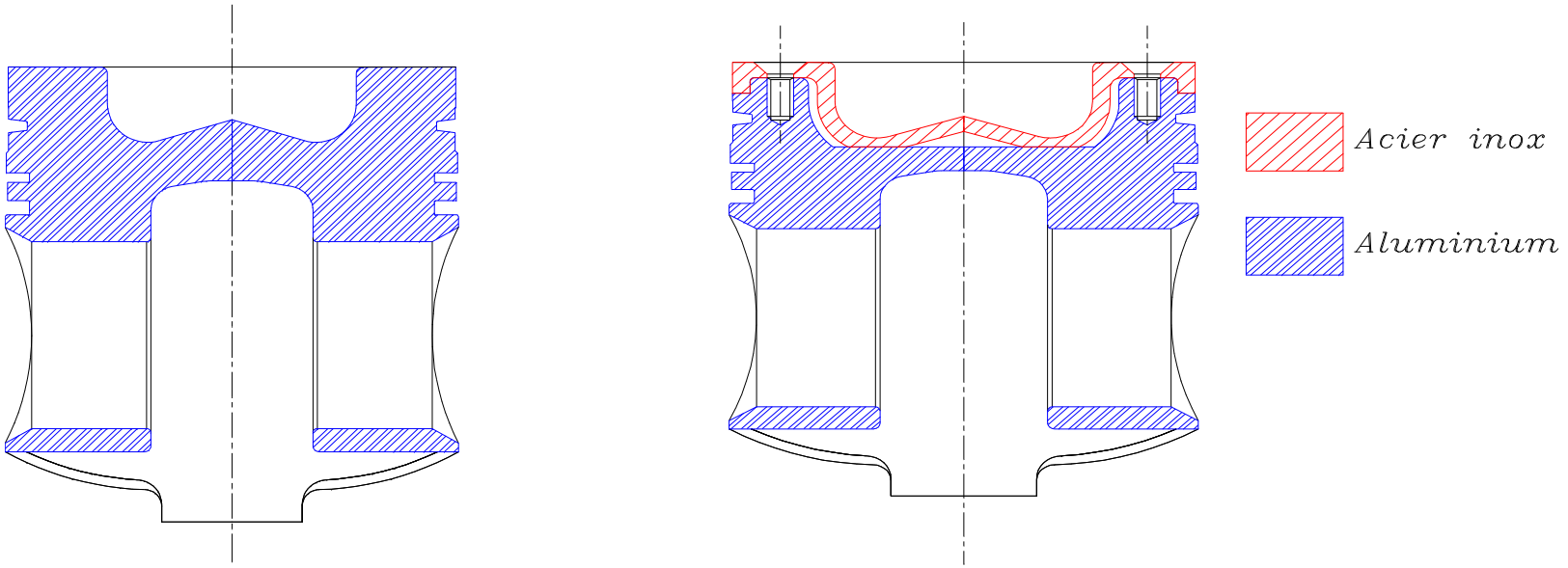


Example of combustion chamber

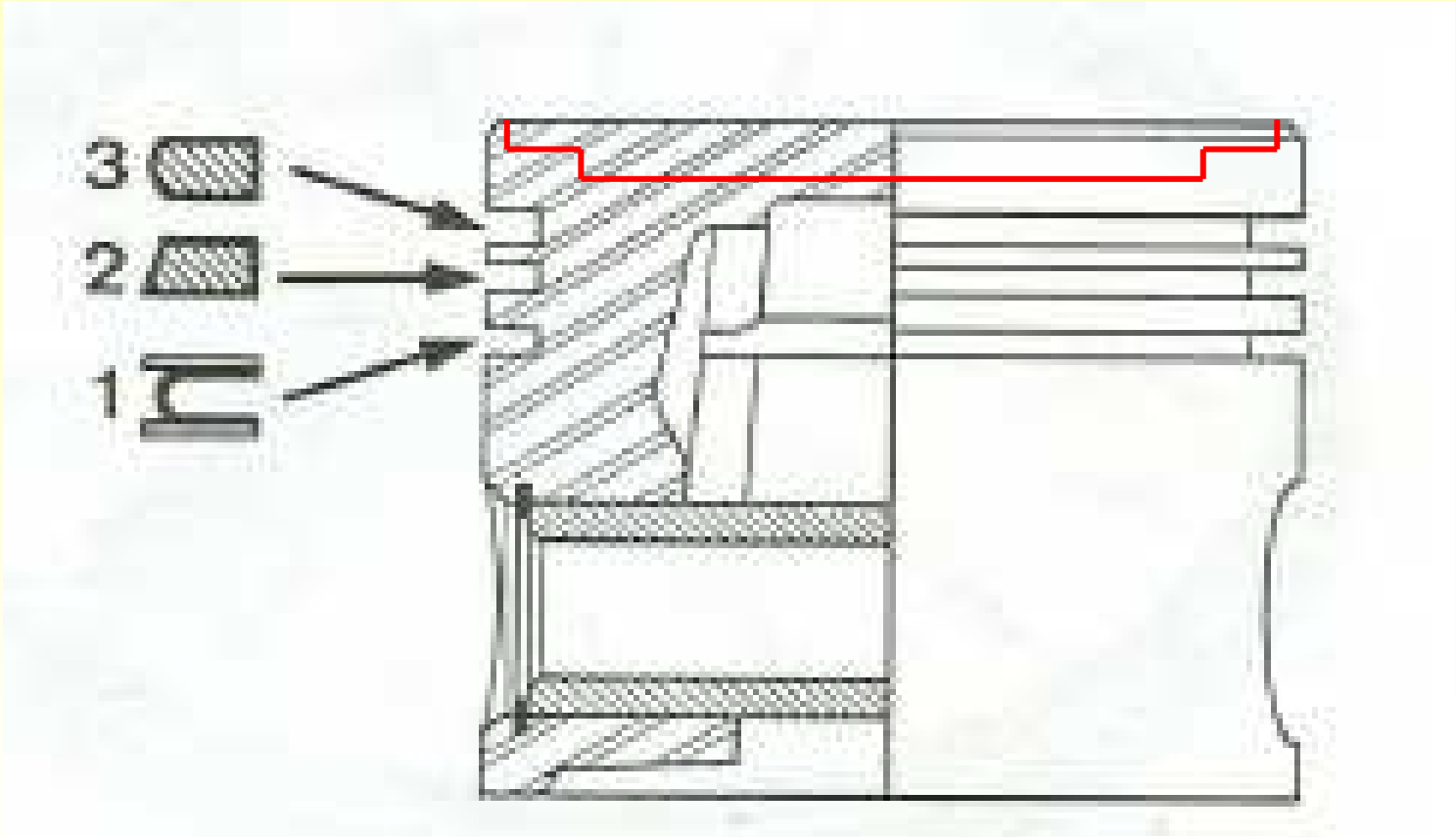
PRINCIPLE OF THE MODIFICATION:

1. *REALIZE A GOOD DRAWING OF THE ORIGINAL PISTON*
2. *DESIGN OF THE STEEL CHAMBER*
3. *DESIGN OF THE PISTON MODIFICATION*
4. *KEEP THE COMPRESSION RATIO (same volume than original)*
5. *THICKNESS MUST BE > 5 mm*
6. *AIR INSULATION GAP MUST BE ~ 2 TO 3 mm*
7. *SCREWS MUST BE « 10 or 12 » HARDNESS QUALITY (not 6 or 8)*
8. *SCREWS MUST BE WELDED CORRECTLY TO THE CHAMBER STEEL*

Example of combustion chamber

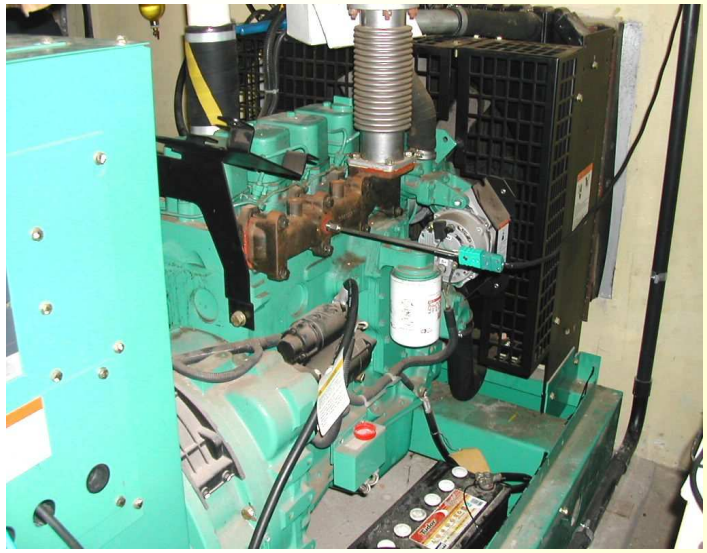


Example of combustion chamber

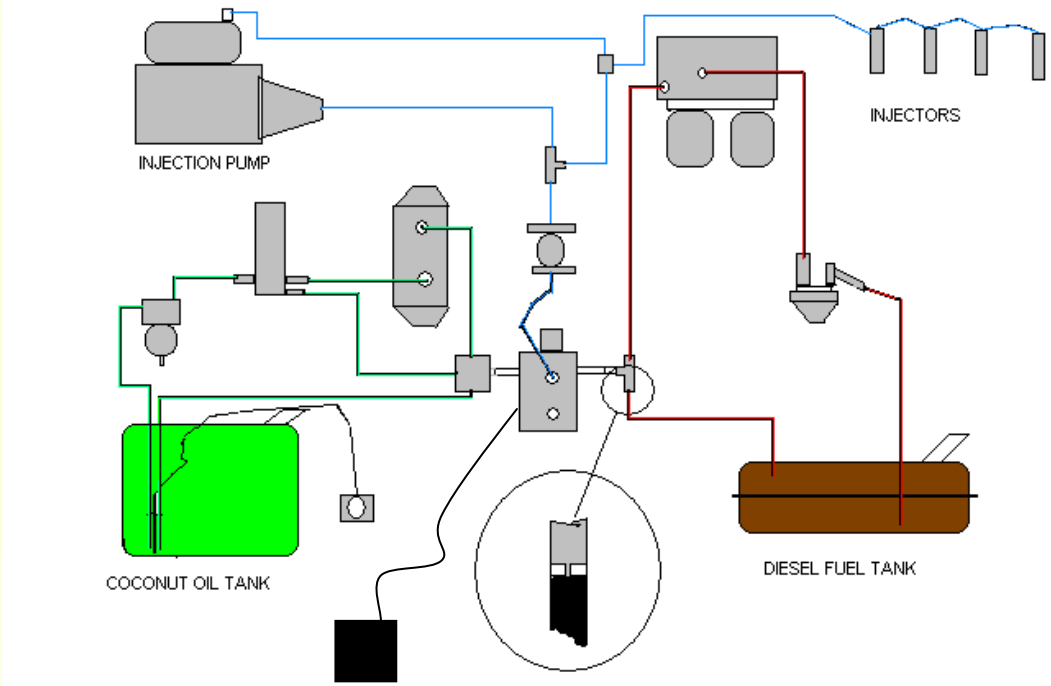


DIESEL DIRECT INJECTION **CRUDE PALM OIL**

SYSTEM OF DOUBLE CIRCUIT or 2 TANK SYSTEM



Genset Cummins 60 KVA (Brazil, 2009)



Control module

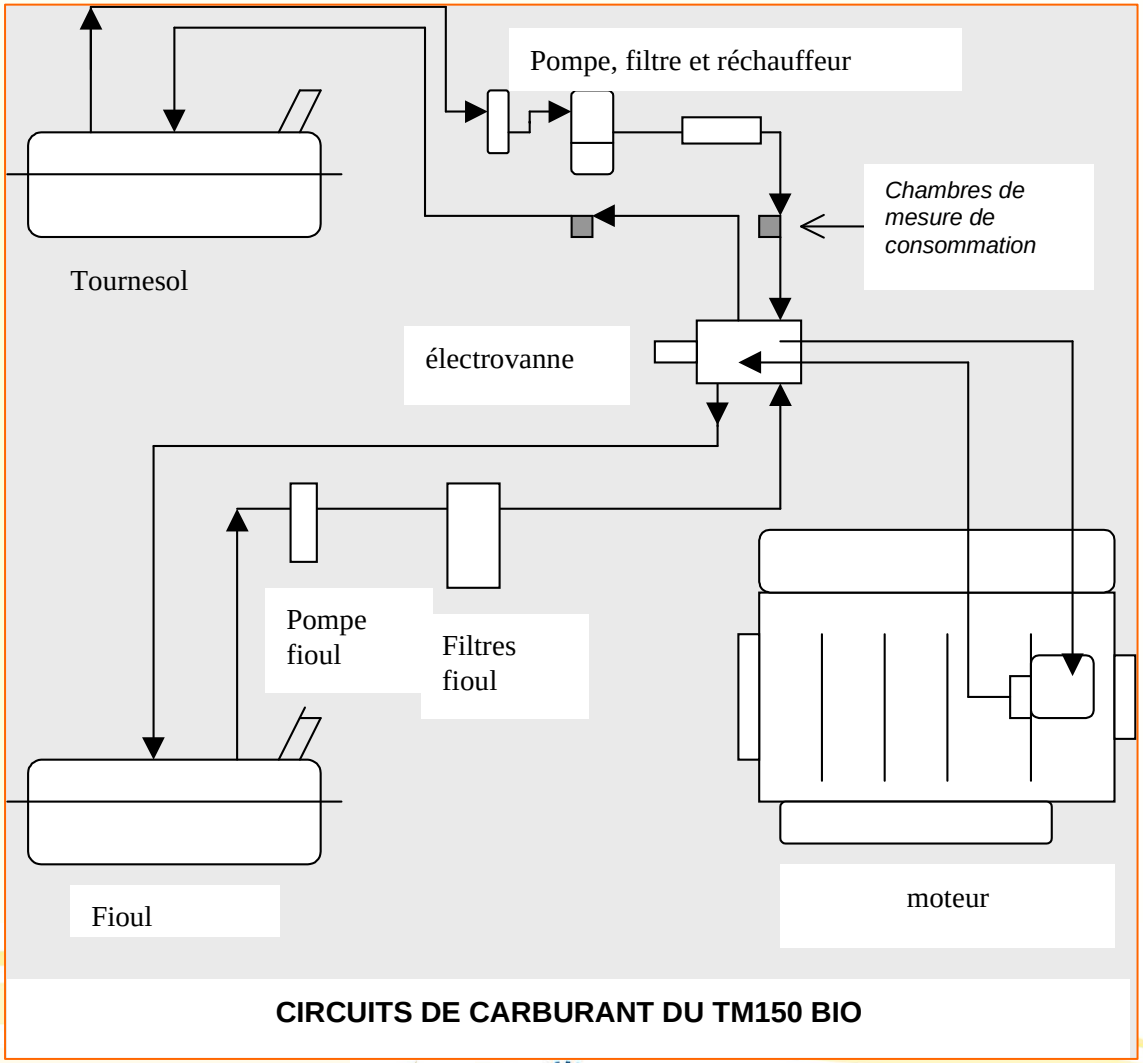
Running on Diesel Fuel from 0 to 30 KVA (load < 50 %)

Running on pure Palm Oil from 30 to 60 KVA (load > 50 %)

DIESEL DIRECT INJECTION SUNFLOWER OIL

CIRCUIT OF 2 TANK SYSTEM

Renault dci 270 Ch (2006)



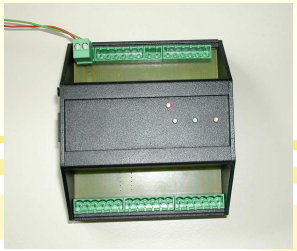
CIRCUITS DE CARBURANT DU TM150 BIO

DIESEL DIRECT INJECTION SUNFLOWER OIL

électrovannes

KIT for SYSTEM OF DOUBLE CIRCUIT

Renault dci 270 Ch (2006)



Coconut Oil for Electricity Generation in the Pacific Examples

Dr. Gilles Vaitilingom

Biofuels Seminar. 15 June 2009. FIT, Suva.
Fiji Department of Energy and Fiji Institute of Technology

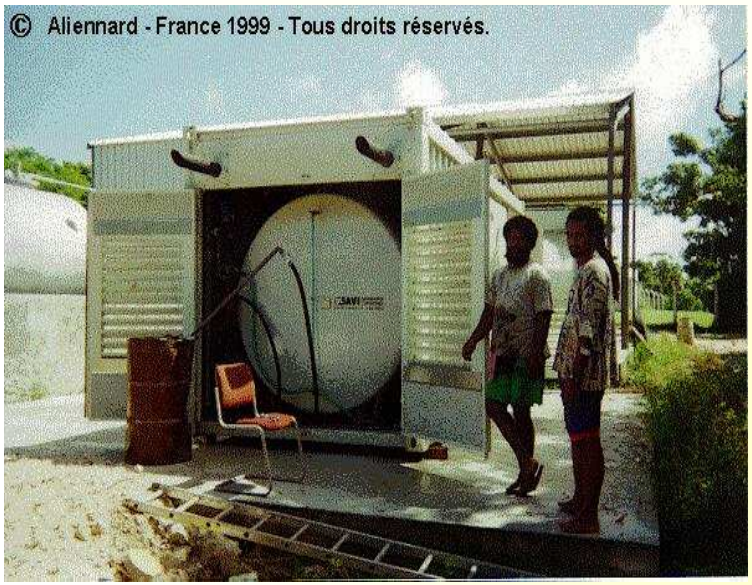
COCONUT OIL IN AN IDI ADAPTED DIESEL ENGINE

COMMUNE D'OUVEA

1995, first Ouvea GENSET. 90KVA

New Caledonia

COCONUT OIL IN AN IDI ADAPTED DIESEL ENGINE



1999, GENSET 200KVA

DESALINATION PLANT, OUVEA-NEW CALEDONIA

COCONUT OIL IN A DI ADAPTED DIESEL ENGINE

In specifically designed engines

2004 GENSET. 300KVA

Power Station of ENERCAL (Utility)

COCONUT OIL IN DI MODIFIED DIESEL ENGINE

2004 GENSET. 300KVA
Power Station of ENERCAL (Utility)

COCONUT OIL IN DI MODIFIED DIESEL ENGINE

2004 GENSET. 300KVA
Power Station of ENERCAL (Utility)

MIXTURES OF FCCNO with DIESEL FUEL

IN STANDARD DIRECT INJECTION ENGINES

BUT RUNNING ON CNO only WHEN LOAD > 50 %

4MW MAN 9L32/40 generators on blends fuel/coconut oil
UNELCO Port Vila - 2004

MIXTURES OF FCCNO with DIESEL FUEL
IN STANDARD DIRECT INJECTION ENGINES

BUT RUNNING ON CNO only WHEN LOAD > 50 % => > 200 KVA

Cummins genset , 400 KVA, 10-20 % CNO in DIESEL FUEL

Savai'i EPC Power station, Samoa (2005)

CRUDE COCONUT OIL AS FUEL

IDI ADAPTED ENGINES

RURAL ELECTRIFICATION:

Fiji: Vanuabalavu 80 KVA* (2000) & Welagi 45 KVA (2001)

Coconut Oil as fuel (10 nuts = 1 litre equivalent Diesel Fuel)

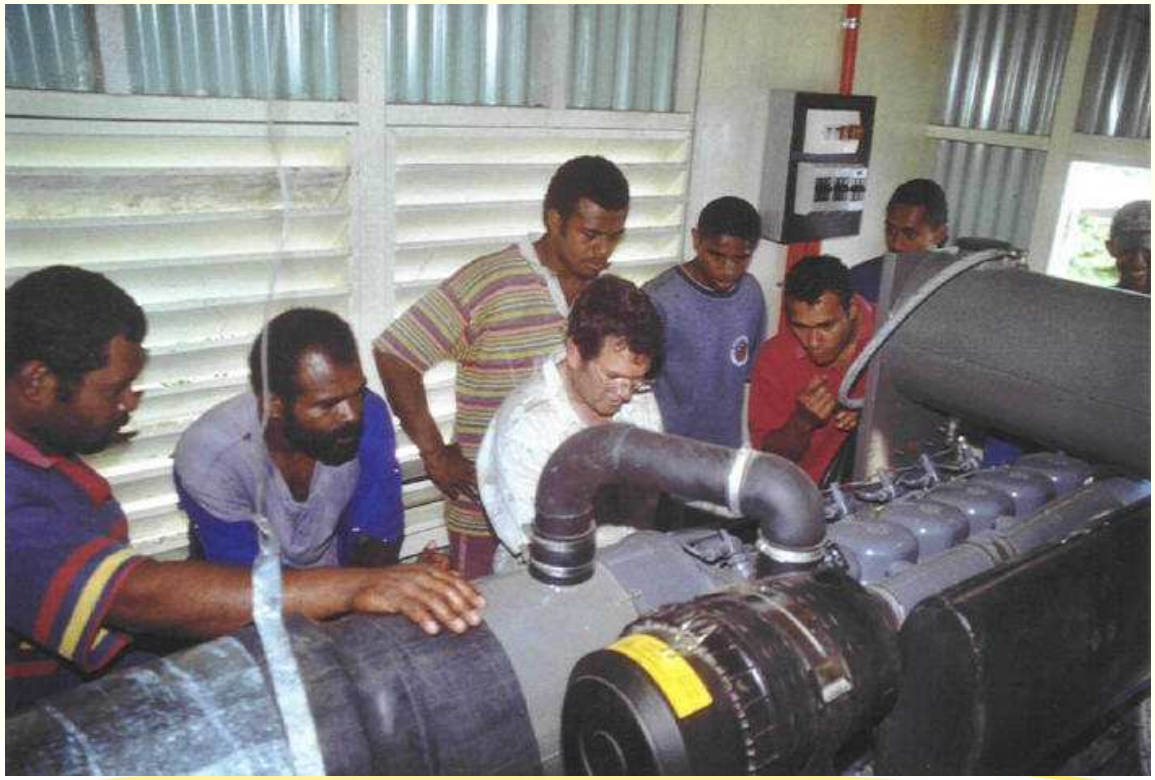
** First place in the World to produce grid electricity with its own vegetable oil (April 2000).*

PURE VEGETABLE OILS AT SMALL SCALE LEVEL

The pre-filtered coconut oil (drum on the left) is pumped by an electrical driven-pump (between drum and filter) and pushed through a flow line bag-filter (on the right).
The hose at the bottom right is connected to the coconut oil main tank of the generator.

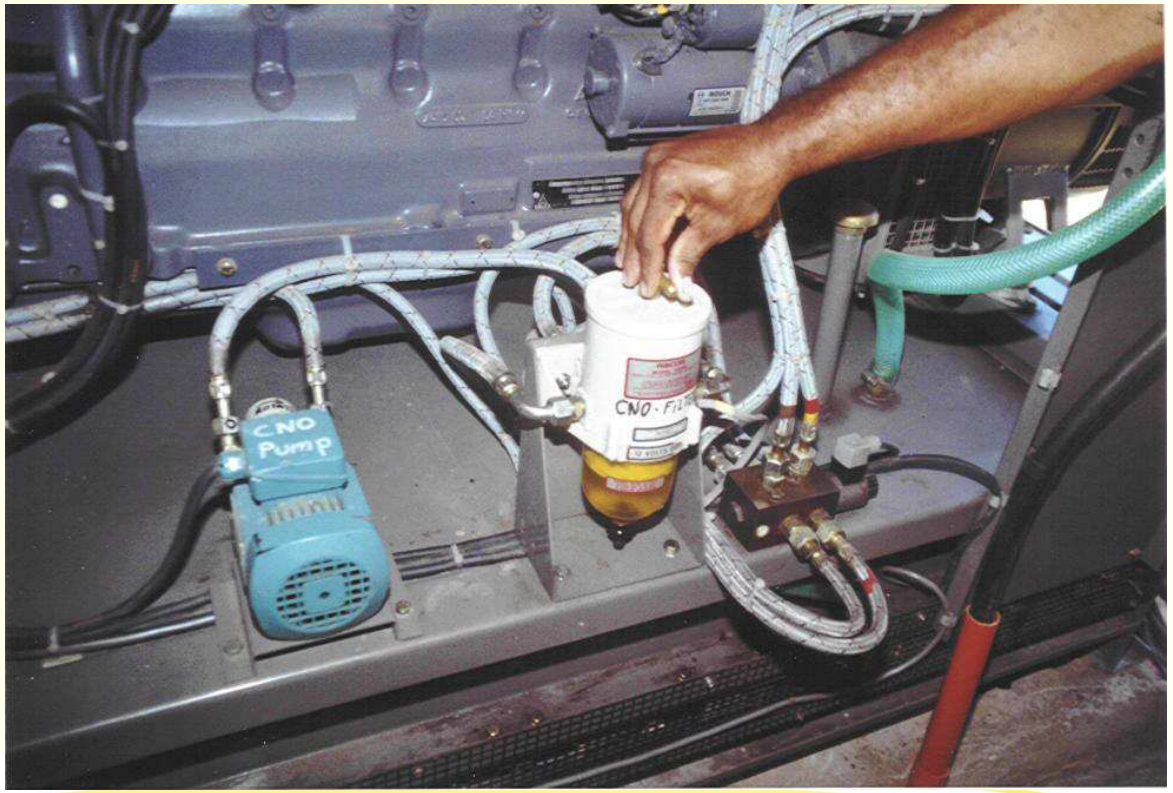
COCONUT OIL FOR ELECTRICITY GENERATION

GOOD TRAINING



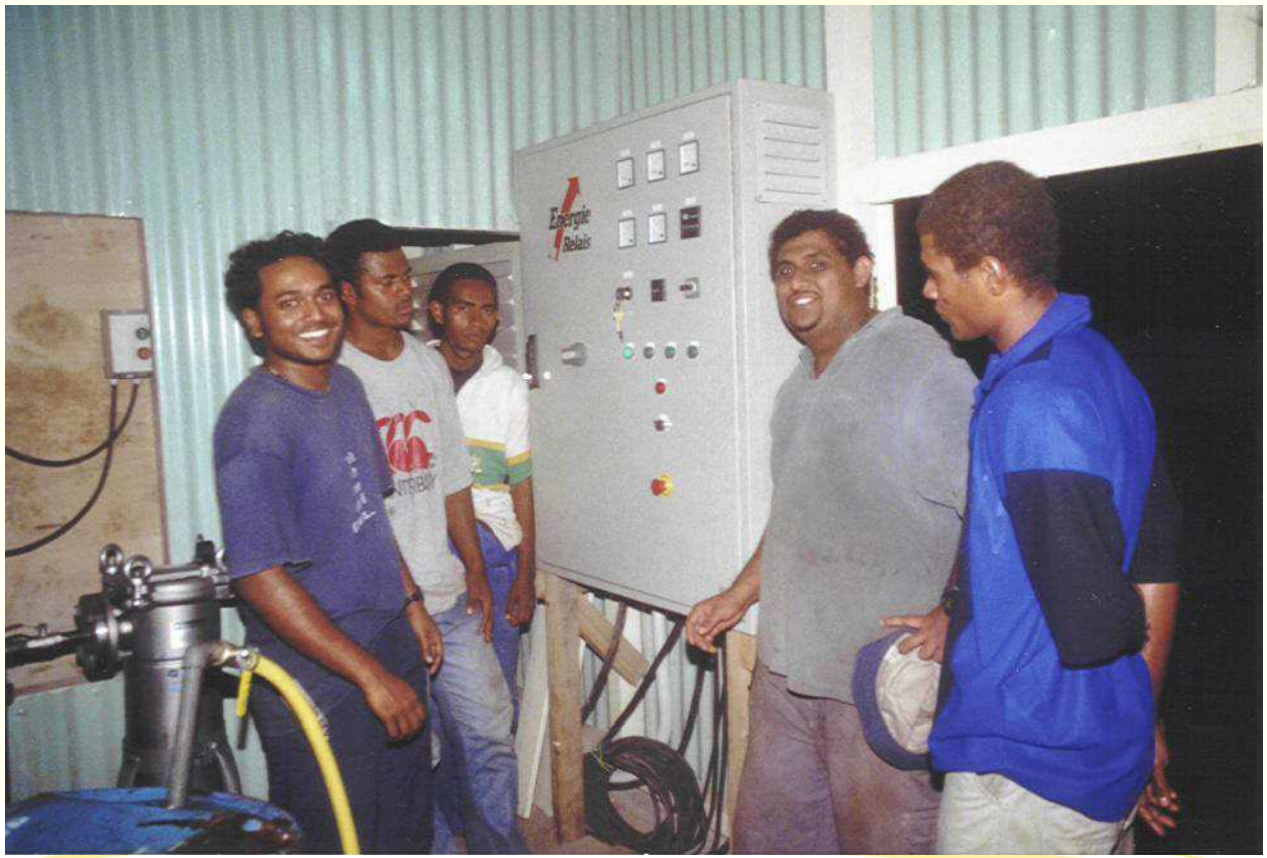
COCONUT OIL FOR ELECTRICITY GENERATION

GOOD MAINTENANCE



COCONUT OIL FOR ELECTRICITY GENERATION

MAKE PEOPLE HAPPY !



DoE staff at the very starting of Welagi genset with coconut oil (July 2001)

Vinaka!

THANK YOU FOR ATTENTION!

MERCI POUR VOTRE ATTENTION !